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ABSTRACT

Computer-assisted instruction (CAI) has become sufficiently widespread to require attention to the relationships between its costs, administration and benefits. Despite difficulties in instituting them, quantifiable cost-effectiveness analyses offer several advantages. They allow educators to specify with precision anticipated instructional loads, to conduct valid long-range planning, to set criteria and goals against which instructional delivery can be measured, and to develop common bases for comparison of instructional alternatives. Cost-effective analyses for the design, development, and delivery of CAI can be based upon the specifications of cost derived from conclusions drawn from given features inherent in the instructional matrix and from postulates which can be reasonably adopted in the light of these given. Use of the analyses assists the educational planner in developing teacher-absent media as a replacement for repetitive personal instructional contact. (PB)

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A MATHEMATICAL MODEL FOR PROJECT PLANNING AND COST ANALYSIS IN COMPUTER ASSISTED INSTRUCTION

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I. DISCUSSION

Computer Assisted Instruction (CAI) is a complex interdisciplinary form of teaching which calls upon expertise in a number of fields. Much emphasis has been placed on the aspects of psychology, education, and computer science, but substantially less attention has been paid to the relationship among costs, administration, and benefits of CAI. It is plausible but admittedly argumentative to speculate that time spent in the pursuit of the psychological and educational aspects of CAI is more akin to pure research, since the findings may be cumulative, where an exhaustive cost analysis could be outmoded by the announcement of yet another computer with a different price. That a cost analysis is perishable, however, does not remove the burden of dealing with its components from the shoulders of the administrator or project planner.

To complicate the issue further, the domain of CAI is not clearly defined by its users. While it is possible to define CAI as "any use of a computer in the instructional process" (which would include such uses as schedule optimization and payroll accounting), most individuals involved in CAI would probably define it as "a two-way interaction between the learner and a computer which results in human learning." Even within this latter definition there are three general types of CAI: drill and practice, tutorial instruction, and environment simulation. These are definitely different levels of interaction (although many would point out that drill and practice is not instruction at all in the sense of teaching something new), and their mention in a discussion of cost analysis is important because different kinds of interaction require significantly different preparation time, and, where personnel are concerned, time is money.

The use of cost/effectiveness analysis is further diminished because of a number of other factors. First, educational administrators are frequently intimidated by and insufficiently prepared to use this type of accounting. Second, it is usually arbitrary to nominate, much less to quantify, the benefits of CAI. Third, the entire field is generally regarded as experimental (or at least "young") and hence liberal cost concessions may be rationalized. Fourth, it is frequently difficult to identify which costs are solely attributable to CAI. And finally, fifth, the design, development, and delivery of CAI may so grossly exceed the limits of even the best planned projects that the prospect of facing the cost overruns may encourage the "ostrich" syndrome of ignoring the issue.

Lest this picture be painted too bleakly, it must be noted that a number of trends seem to be gaining both strength and popularity in educational (or at least CAI) circles. First only by virtue of its widespread lip service is a class of approaches to problems and/or procedures known as the "Systems" approach. Regretably, the reputation of this class of techniques has been tarnished by the inappropriate use of the word "systems." Nonetheless, the origins and currently more "pure" uses of Systems Analysis suggest and sometimes trumpet its remarkable value in education. The work that came out of Stanford Research Institute around 1965 (plus or minus three or four years, depending on your perspective) and the Midwest Administration Center (University of Chicago) since about 1964 are ample cases in point. Second, the recent popularity of "accountability" in education will probably bring some greater focus on quantification of performance in educational systems at all levels. Third, and perhaps most important, is the recent recognition of the contributions made by John Carroll in his (mathematical) model of school learning, which has been verbalized and renamed by Bloom as "mastery learning."

II. ADVANTAGES AND PITFALLS OF QUANTIFYING CAI AND INSTRUCTION

In its early development, CAI was characterized--and for good reasons properly so--by experimentation and expansion through the "back door." That is, projects began as experimental research with one or two terminals, a few modifications to an existing software package, and some hypotheses. As results came in, more and more questions were raised, these "twentieth century" teaching techniques were publicized, and more money was granted for further research. As a result, expansion occurred by borrowing a piece of equipment here, trying a new software modification there, and the general net result was a hodge-podge of assorted hardware, software, and results.

Since that time many advances have been made. IBM assumed an early leadership in the field, dedicating a research laboratory, Instructional Systems Development Division (ISDD) in Los Gatos, California, and the 1500 Instructional (Computer) System was announced. This was rapidly followed by a number of computer company/publishing house mergers and the race was on. Incidentally, the origin of the Association for the Development of Computer-based Instructional Systems (ADCIS) was the 1500 Users Group. The attention to CAI reached a peak around 1968, and publicity after that time began to stress production and utility rather than "revolution" and references to "space-age technology." The net result is that now much experience has been gained, substantially more rational (and, hence, less sensational) approaches to CAI are offered, and the sophistication of both CAI practitioners (for lack of a better word) and the hardware/software vendors has reached a level where a variety of possible approaches may now be specified, compared and selected. The onus of reponsibility is now upon the administrator/project planner to quantitatively and qualitatively identify his instructional needs in a metric which correlates with what can be supplied by CAI--a metric which may be (and probably is) foreign to administrators.

The advantages of quantifying CAI and instruction include 1) greater precision in anticipating instructional loads and demands so that these requirements may either be met or accommodated through schedule juggling or other rearrangements of resources, 2) efficient, valid, and reliable long-range planning, 3) criteria and goals against which production and delivery "quotas" may be measured, 4) the development of common bases of comparison among methods of instruction and learning so that cost/effective decisions may be reached. These advantages correlate closely with the kinds of questions administrators must answer, such as 1) during the week of January 21, 1974, 150 freshmen will be using the terminals heavily to prepare for their final on the 25th, but also 145 sophomores will start a sequence on CAI; do we have enough terminals and computer time available to handle these needs? 2) If we continue to prepare CAI programs at this rate will we have enough terminals to deliver the materials during the school year 1974-1975? 3) Last year we projected that we would produce ten more CAI program-hours but we produced only eight. Should we hire another programmer in order to have all these materials developed by the fall of 1976? 4) the CAI program developed for course A was expected to cost less in preparation and delivery than the expense of individual tutoring by an instructor and yet there was a cost over-run. Do we have sufficient time, space and cost reserves that we can handle a similar situation in the development of course B?

An attempt at quantifying the instructional environment should not be reviewed as the utmost pinnacle of precision in educational planning, however. No matter how precise or accurate the analysis, there will always be qualitative "border" conditions that must be examined and, in many cases, are apparent only

a posteriori from empirical evidence. For example, it is possible that replacing a lecture with a CAI program might ignore other facets than the measureable cognitive outcomes, such as the adoption of the attitudes or preferences of an instructor. It is entirely conceivable that a well designed individualized course delivered via CAI (or any other teacher-absent instructional medium including books, videotapes or slides, for that matter) may allow cramming to pass a test without providing sufficient time for memory consolidation and, hence, long-term retention. Another pitfall that may accrue from an over-emphasis or over-reliance on quantitative indexes of instruction and learning is characterized by the phrase "more is better." With the advances made each day in every field, the pressure to lengthen curricula and to include more and more material is tremendous. As a result, the temptation to require students to consume more information in the same length of time can be more easily satisfied if it means erasing one number and replacing it with a higher number in a quantitative model. In this last point lies the intimate feedback afforded by the classroom instructor-student relationship, because the primary point of contact (the instructor) may rightly balk at increased information transmission without a commensurate increase in contact hours.

Quantitative models are powerful scientific tools for increasing the precision and predictability of what has for centuries been the nebulous art of teaching. Their use and results can both provide the administrator with greater planning precision and, if individualized instruction is indicated, they can relieve the instructor of the tedium of simple information transmission and repetition. So long as these models are clearly perceived as tools and as means to an end, and while there are constant reminders of the qualitative aspects of student learning, pitfalls will be avoided.

III. THE SPECIFICATION OF PERSONNEL COSTS

At the most basic level, one cannot begin to slice a pie until the pie is at least identified. This statement is meant to sound neither facetious nor trivial. Those who attempt even a crude cost analysis frequently predispose themselves to needless frustration and searching by failing to clearly identify from the beginning just exactly what the task is. This is not to suggest that it is necessary to become totally locked into a single domain, but rather that it will be helpful in the process of cost accounting to write down some general guidelines to aim the approach. Certainly flexibility is needed to expand or contract the range of an analysis, but if guidelines are committed to paper, this at least requires some second thought and hopefully a grounded justification for modification of the domain.

For the sake of this discussion, the domain of analysis will be the design, development, and delivery of tutorial computer assisted instruction, from its conception in the mind of a prospective author to its consumption by a student in the target population. It is not the intention of this paper to endorse anything but a proposed method of cost accounting. There is no doubt that the strategies used for illustration will be criticized, and I implore the reader to ignore the specific content used to make the points if they are contrary to one's preference. The following discussion of costs will proceed in as small steps as possible in order to explicitly identify each component of the cost framework. The steps will be made on the basis of givens (G), postulates (P), examples (E), and conclusions (C).

G.1: COSTS ARE TO BE MINIMIZED

G.2: TASKS WILL BE PERFORMED BY THE LOWEST-PAID PERSON CAPABLE OF PERFORMING THAT TASK.

P.1: CONTENT SPECIALISTS ARE NOT COMPUTER-SOPHISTICATED.

From the above points, it is possible to conclude that:

C.1: AT LEAST TWO TASK PERFORMERS ARE NECESSARY TO ACHIEVE THE DESIGN OF INSTRUCTIONAL SOFTWARE: A "provider of the content," and a "translator of the content into a computer program."

P.2: PERSONNEL PERFORM TASKS IN RATIOS OF TIME.

E.1: It is plausible to consider a working relationship between a content specialist and an educationally sophisticated translator or programmer where the latter may spend, say, eight hours on organization and translation per hour of specification of the content. Consequently, at least this one quantitative relationship can be used in later anaysis.

To build further:

P.3: A JOB UNIT MAY BE DEFINED AS THE SMALLEST RATIO OF WHOLE NUMBERS OF PERSONNEL TIME.

E.2: OUR JOB UNIT would thus be set for this example at 1:8.

G.3: A CONVENIENT UNIT OF ANALYSIS IS THE STUDENT CONTACT HOUR (SCH) (i.e., one student interacting with a computer terminal for one clock hour).

P.4: AN AVERAGE OF $\underline{n}$ JOB UNITS IS REQUIRED TO PRODUCE ONE SCH.

E.3: For the sake of this discussion, let us set the number of job units per SCH at 6. Thus, to produce enough code to keep, say, an average student in the target population "busy" for one hour at a terminal, it will be necessary to invest (allocate, etc.) 6 hours of content time and 48 hours of translator time.

G.4: THE GOAL IS TO DEVELOP 258 HOURS OF CONSUMABLE CAI.

E.4: The intent of G.4 is to imply that regardless of the number of students in our target population, that each student (more realistically, the average) will spend a total time of 258 hours at a CAI terminal. Note especially that no specification has yet been made, nor does it need to be made at this point, of the size of the student population.

C.2: TO PRODUCE 258 HOURS OF CAI, IT WILL BE NECESSARY TO SPEND:

258 Hours x 6 Job Units/Hour x 1 Hour for Content = 1,548 Content Hours

258 Hours x 6 Job Units/Hour x 8 Hours for Translation = 12,384 Translation Hours

P.5: OF THE 2080 WORKING HOURS PER YEAR (52 WEEKS x 40 CLOCK HOURS PER WEEK) APPROXIMATELY 1840 ARE ASSIGNABLE TO WORK (given 4 weeks vacation plus 2 weeks for miscellaneous holidays, sick time, etc. Hence, 46 weeks x 40 hours/ week = 1840)

Dividing each extension of hours (1,548 and 12,384) by 1,840 results in the number of whole "work-year equivalents" needed to perform the respective task. Multiplying that by 12 (number of months per year) results in full-time man-months.

$$\frac{1548}{1840} = 0.841 \times 12 = 10.09$$

$$\frac{12,384}{1,840} = 6.730 \times 12 = 80.76$$

C.3: 258 HOURS OF CAI WILL REQUIRE TEN FULL-TIME MAN-MONTH EQUIVALENTS OF CONTENT PERSONNEL.

C.4: 258 HOURS OF CAI WILL REQUIRE 80 FULL-TIME MAN-MONTH EQUIVALENTS OF TRANSLATION PERSONNEL.

Note that our original ratio of 1:8 is still preserved. At this point, only one more step must be made to finally proceed from these units to an expression of cost.

G.5: CONTENT PERSONNEL COST $20,000/YEAR.

G.6: TRANSLATION PERSONNEL COST $9,000/YEAR.

C.5: THE COST OF PRODUCING 258 HOURS OF CAI IS:

$$\begin{aligned} 10 \text{ months} \times \$20,000/12 \text{ months} &= \$16,667 \\ + \ 80 \text{ months} \times \$\ 9,000/12 \text{ months} &= \underline{60,000} \\ &\quad \$76,667 \end{aligned}$$

NOTE: The costs of physical space, supplies, and computer time are not included in this analysis.

At this point, data are now available for some planning, in units which are presumably commutative (if three men can dig a hole in seven hours, how long will it take . . .). At the risk of over illustration, these data now suggest that one content specialist, working with 8 translators (technically 8.07) could accomplish this task in 10 months. Or, more realistically, it will take e.g. 10 content specialists, each working 10% time (approximately 4 hours/week) on CAI materials development, 10 months to develop 258 hours of CAI, given 8 translators (IF--and it is a very tenuous assumption--our specification of six job units per SCH is accurate). The variations are myriad, within certain logical constraints (for example, just imagine the pandemonium of 100 content specialists and 800 translators working non-stop for 17.6 hours . . .).

On the basis of the foregoing argument, this analysis can be expressed in terms of a general-form model as follows:

$$\frac{CAI \times JU \times R_A}{1840} = \$A/YEAR = \$A$$

where CAI = the production goal for the development of CAI in units of hours of nonredundant consumption per student,

JU = number of Job Units required to produce one consumption hour of finished-produce CAI material,

R_A = one element of the personnel time ratio,

$A/YEAR = the annual salary for the job function defined by "A",

$A = estimated project cost for job function "A".

NOTE: By analogy, project cost for job function "B" can be calculated by replacing R_A and $A/year with R_B and $B/year.

E.5: Based on the above hypothetical figures, our calculation of project costs would appear as follows:

(A) $\frac{258 \times 6 \times 1}{1840} \times \$20,000 = \$16,820$

(B) $\frac{258 \times 6 \times 8}{1840} \times \$\ 9,000 = \frac{60,570}{\$77,390}$

NOTE: the difference between this figure ($77,390) and that on the previous page ($76,667) ir due to rounding error. These illustrations are based on the theory of New Math that it's the form that's important.

IV. THE SPECIFICATION OF DELIVERY COSTS

Given that:

G.7: n' hours of consumable "finished product" instructional materials are developed.

Our question now becomes, "How may these products be delivered to students? The useful unit of calculation for this problem is the Student Contact Hour (SCH), since this is the commutative element representing the product of the number of students and the number of (average) consumption hours per student. There are border conditions or constraints on the use of these units, however. Our basic question centers around cost, of course, but the determination of cost is reliant on the specification of numerous other interacting factors, each with its own cost. The constraints on this analysis are rather logical. For example, denying for the moment the question of equipment reliability, it is obvious that it is unnecessary to provide more delivery stations (be they study carrels, computer terminals or books) then students. On the other hand, the mathematical minimum number of stations is equal to those needed if they were used 24 hours per day assuming that there is no time lost between students.

For an illustration of this analysis, let us again take the earlier-referenced 258 hours of CAI to be consumed per student. This example will be more realistic if it is further stipulated that these hours address themselves to different levels in a four-year curriculum, and that each class year has a different enrollment.

G.8:

Class Year	CAI		# Students		SCH
1	150	(x)	150	(=)	22,500
2	50	(x)	140	(=)	7,000
3	30	(x)	130	(=)	3,900
4	28	(x)	120	(=)	3,360
TOTAL	258		540		36,760

Our task is to now provide 36,760 Student Contact Hours during, for example, the coming University year.

G.9: THE "UNIVERSITY YEAR" IS 30 WEEKS.

G.10: STUDENT ACCESS (loading schedule) WILL BE HOMOGENEOUS FROM WEEK TO WEEK.

There are now two ways to calculate our minimum "delivery load" per week. If we assume random use of learning stations, then students from class years can be combined. If, however, students will access materials class year by class year (freshman from 8 a.m. to 10 a.m., sophomores 10 a.m. to noon, etc.), we will have to accommodate the peak load since, by definition, all other access will be less demanding. Let us assume this latter, more stringent case for the sake of this argument. Examination of the table given in G.8 above indicates that class year 1 will be the most demanding on our delivery system. Given the information in G.9 and G.10, it is now possible to calculate the delivery load per week, as follows:

P.6: $$\frac{22{,}500 \text{ SCH/Univ. Year}}{30 \text{ Weeks/Univ. Year}} = 750 \text{ SCH/Week}$$

Let us further assume that the delivery facilities will be reserved for the exclusive use of freshmen 5 hours per day, 5 days per week. Our elements for analysis are now: 750 SCH/Week, 150 students, and 25 hours/Week. If we now impose the realistic constraint that our stations will operate at 80% efficiency (a desirable but probably unattainable goal) due to equipment down time, changing from one student to another, etc., our availability hours now become 20 instead of 25. Since SCH is a unit which describes supply as well as demand, it is now possible to calculate the number of learning stations that are needed to deliver 750 SCH/Week on a 20-hour/Week basis.

P.7: $$\frac{750 \text{ SCH/Week}}{20 \text{ Hours/Week/Station}} = 38 \text{ Stations}$$

The calculation in P.7 now provides the data from which the cost for delivery stations can be calculated (number of stations times cost per station). CAI delivery, however, requires something to "drive" the terminals, namely, a computer. It is especially in the analysis of computer costs that it is necessary to differentiate between fixed and variable costs.

For the sake of this discussion, let us assume that we will purchase the computer outright. Furthermore, let us make the assumption that we are responsible only for the minimum personnel necessary to keep the operation current.

Hence:

P.8: Computer Operations Staff:

(1) Systems Programmer @ $17,000/Year
and (2) Computer Operators @ 9,000/Year
and (3) Keypunch Operator @ 6,000/Year

Theses personnel costs can then be combined with hardware costs to estimate the cost per year of delivering CAI.

E.6: One time Costs:

Computer Purchase		$500,000
Learning Stations	38 @ $5,000	190,000
		$690,000

Annual Costs:

Computer Operations Staff		
1 @ $17,000	$17,000	
2 @ 9,000	18,000	
1 @ 6,000	6,000	
Sub-total	$41,000	$ 41,000
Systems Software Updates, and Miscellaneous Yearly Costs		$ 8,000
		$ 49,000

It is now possible to postulate a simple model for delivery costs per year, given that we also specify or identify a service life of the machine (explicitly omitting reference to the service life of the software).

P.9: CAI Delivery Cost/Year = OTC + (m x VC)

where OTC = one-time costs and VC = variable costs
m = number of years of operation

E.7:

m	Formula	Delivery Costs
1	$690,000 + (1 x $49,000)	$739,000
2	690,000 + (2 x 49,000)	788,000
3	690,000 + (3 x 49,000)	837,000
.		
.		
.		
10	690,000 + (10 x 49,000)	1,180,000

V. A SIMPLE COST/BENEFIT MODEL

The preceding sections have now provided all the necessary information from which a simple cost/benefit analysis can be made. In this discussion, only the quantitative unit of student contact hours (SCH) will be identified as the unit of benefit, and the tenuous assumption will be made (for the sake of the example) that one SCH delivered by CAI is equal to one SCH delivered in some other manner (for example, in a lecture). In this analysis it will be necessary to calculate all costs of design, development, and delivery on the one hand and the benefits (in this case consumed SCH's) on the other. Hence:

E.8: COSTS:

OTC Design and Development		$ 66,600
OTC Delivery		690,000
Variable Delivery Costs (where m = number of years)	m x	49,000

"BENEFITS"

m(Years) x 36,760 SCH/Year

We can now combine the one-time costs, and establish a table of cost per SCH which will then provide us with a common basis for comparing CAI with other information delivery media.

P.10: COST PER SCH EQUALS:

$$\frac{OTC = m(VC)}{m(SCH/Year)}$$

E.9: COST/BENEFIT FOR THREE YEARS IS:

$$\frac{\$756,600 + (3 \times \$49,000)}{3 \times 36,760} = \frac{\$903,600}{109,280_{SCH}} = \$8.27/SCH$$

Calculating these figures over longer periods of time results in lower costs per SCH, ignoring for the moment the probable need to revise materials, which would add a variable cost to the design and development component. A table of these cost/benefits is presented below:

E.10:

YEARS	COST/SCH	DIFFERENCE PER YEAR
1	$ 21.92	
		$ 10.30
2	11.62	
		3.35
3	8.27	
		1.79
4	6.48	
		1.03
5	5.45	
		0.69
6	4.76	
		0.49
7	4.27	
		0.36
8	3.91	
		0.29
9	3.62	
		0.23
10	3.39	

Examination of the table in E.10 indicates that the cost per SCH diminishes each year, and that the cost saving per year becomes less and less. This table may be interpreted to mean that if all materials were developed, and then delivered for only one year, without any cost salvage of the hardware or software, that it would have cost the operation $21.92 per hour each student sat at the terminal. While this suggestion would appear to be sheer folly, it is really only a matter of degree, since only the inexperienced would suggest that equipment changes will never be made, or that there is no salvage value from displaced equipment. Lest this analysis seem harsh, it is necessary to stress that nowhere has this model accounted for the cost saving derived from not paying faculty to teach this same material in the classroom. More realistically, the incremental cost of delivering the material should be examined. For example, assuming that the cost per SCH for classroom delivery is $6 in professorial salary, then running this operation for 4 years or less would be economically foolish, where its operation for 5 years or more would probably be less expensive (assuming that faculty salaries remain constant).

It is to be stressed that the Cost/SCH entries in E.10 are to be interpreted as average cost for all years to date, and not as cumulative costs. For example, it is not the case that this instruction would cost $21,92 for the first year regardless of the number of years of the project.

VI. DISCUSSION

This paper is designed to stimulate thought about the use of quantification schemes and mathematical models in educational planning in general and in CAI in particular. It came about as a result of a number of pushes and pulls, and its initial application was made by the author in preparing a five-year master plan of the design, development and delivery of individualized instructional materials for the School of Dentistry of the University of Michigan.

Consistent with this author's belief in the use of teacher-absent media to replace repetitive personal instructional contact, this paper also serves to answer the questions of a number of other administrators who asked how one gets from A to M in projecting personnel and equipment needs and how these costs are partitioned and amortized.

Since the time of its original specification (August, 1971) and its first presentation (August, 1972) and now (August, 1973) a number of changes have so modified the original plan that a follow-up contrast between that proposal and current status would appear as one line of text and fifty footnotes per page.

In the final analysis it is hoped that readers will try not to copy these formulae verbatim but to induce from them the approach strategy and to then apply the game plan to their own idiosyncratic problems. Any similar approaches will be warmly welcomed.

VII. A CURRENT PROJECT

Mr. Arun Garg and I are currently working on an analysis plan of time and cost for personnel mixes. Mr. Garg is a member of the staff afforded by the Special Improvement Grant under which current CAI (and other) materials are being developed (USPHS grant number PE01220-02). These following models are presented only as the crudest rough drafts and progress toward their refinement will depend

in part on reactions and comments from readers.

Problem: What is the optimum mix of personnel that results in overall minimization of time?

Given: Task personnel identified as:

C = Content Expert
I = Instructional Programmer
P = Computer Programmer
K = Keypunch Operator
E = Evaluation

Solution 1:

Train any one person to perform all other tasks competently.

S1a: train the content expert to perform all other tasks

$$\Sigma T = \overset{1}{TR}_i + \overset{2}{TR}_p + \overset{3}{TR}_k + \overset{4}{TR}_e + \overset{5}{C}_t + \overset{6}{I}_t + \overset{7}{P}_t + \overset{8}{K}_t + \overset{9}{E}_t$$

Where ΣT = total time

TR = time required to be trained in each job specialty as identified by the subscript

$C_t, I_t, \ldots, E_t$ are the times required to perform each job task.

Note that equation elements 1-4 are training times; TR_c is omitted because it is presumed that the content expert by definition needs no (additional) training ignoring forgetting.

The Cost of this use of personnel is now calculable by multiplying time by cost per unit of time. A priori this model might be rejected if the wage of the content expert were high in relation to that of others. This model is also general form because any subscript can be omitted from the first four elements subject to the constraint that four of the five elements are present and assuming that the person selected to learn the other job tasks is ignorant of those operations.

Solution 2:

Request from each person time performing only his specialty.

S1a: $\Sigma T = C_t + I_t + P_t + K_t + E_t$

This model may seem complete but it fails to include interaction time. For example, C must talk with I, I must explain things to P, etc. Thus, the model must include additonal elements for interaction:

S2b: $\Sigma T = C_t + T_{ci} + I_t + T_{ip} + P_t + T_{pk} + K_t + T_{ie} + T_{pe} + E_t$

where: $C_t, I_t, \ldots, E_t$ are the times required to perform each job task and T_{ij} are times required for interaction between the i-th and j-th personnel task.

Observation of this model indicates that it might be undesirable because certain tasks are joined by an interaction between respective specialties. The presentation of this model at least allows a clear statement of how time is spent so that strategies for influencing the elements can be proposed and/or implemented. For example, it may be possible to reduce or minimize T_{pk} by the development of a standardized set of keypunching instructions as well as a pre-printed key punching form.

The Cost analysis of this model is derived by multiplying respective elements in which time is spent by that person by his respective wage.

These models are briefly presented here for introductory purposes only and are not meant to represent a finished product.